Crustal Deformation Along the Northern San Andreas Fault System
Final Project Report

U.S.G.S Award Numbers 02HQGR0064, 03HQGR0074, 04HQGR0103
Prepared by Douglas Dreger for Mark H. Murray (PI)
University of California, Berkeley, California, 94720
Ph. (510)643-1719; Fax (510)643-5811; dreger@seismo.berkeley.edu

Introduction

The following report was prepared based on Berkeley Seismological Laboratory (BSL) Annual report contributions (2003-2004; 2004-2005; http://seismo.berkeley.edu/annual_report) that were prepared by the PI Mark H. Murray who left the BSL in 2005. This compilation of these reports was prepared by Douglas Dreger.

The San Andreas fault system in northern California includes three sub-parallel right-lateral faults: the San Andreas, Ma'acama, and Bartlett Springs. This northernmost segment is the youngest portion of the fault system, forming in the wake of the northwestwardly propagating Mendocino triple junction where the Pacific, North America, and Gorda (southern Juan de Fuca) plates meet. The Pacific plate moves about 35-40 mm/yr relative to central California across a broad ~100-km zone in northern California. Additional deformation in eastern California and the Basin and Range province contribute to the total relative Pacific-North America motion of ~ 50 mm/yr. The San Andreas fault itself has been essentially aseismic and accumulating strain since it last ruptured in the great 1906 San Francisco earthquake, and no major earthquakes have occurred during the historical record on the more seismically active Ma'acama, and Bartlett Springs faults, which are northern extensions of the Hayward-Rodgers Creek and Calaveras-Concord-Green Valley faults in the San Francisco Bay area. Our earlier geodetic studies showed that the inferred slip rate on the Ma'acama fault ($13^{+4.1}_{-2.8}$ mm/yr) implied an accumulated slip deficit large enough to generate a magnitude 7 earthquake, posing a significant seismic hazard (*Freymueller et al.*, 1999).

Since 2003, we have been resurveying sites measured in our previous studies plus about 40 additional sites, originally surveyed by Caltrans and NGS (*Murray,* 2004). The additional sites are located along the San Andreas fault system just north the San Francisco Bay and will improve monitoring along the Rodgers Creek and Green Valley faults. Most of the monuments were last observed in 1993-1995, so the new observations significantly improve the velocity estimates and models of average interseismic strain accumulation, including possible spatial variations along the fault system. Additional sites in the region between the southern and northern portions of the network are planned for resurveying in the future. The entire network spans the region from Pt. Reyes to Cape Mendocino. Together with planned PBO stations, it forms a primary monitoring network for future observations to detect temporal variations in deformation.

Approach

In this study, we resurveyed the original profiles and added two new profiles to the north and south (Covelo and Healdsburg, respectively, in Figure 1). Most of the monuments were last observed in 1993 or 1995, so the new observations significantly improve the velocity estimates, and we expect they will improve models of average interseismic strain accumulation, including possible spatial variations along the fault system. These 10-station profiles every 50 km from

Pt. Reyes to Cape Mendocino form a primary monitoring network for future observations to detect temporal variations in deformation.

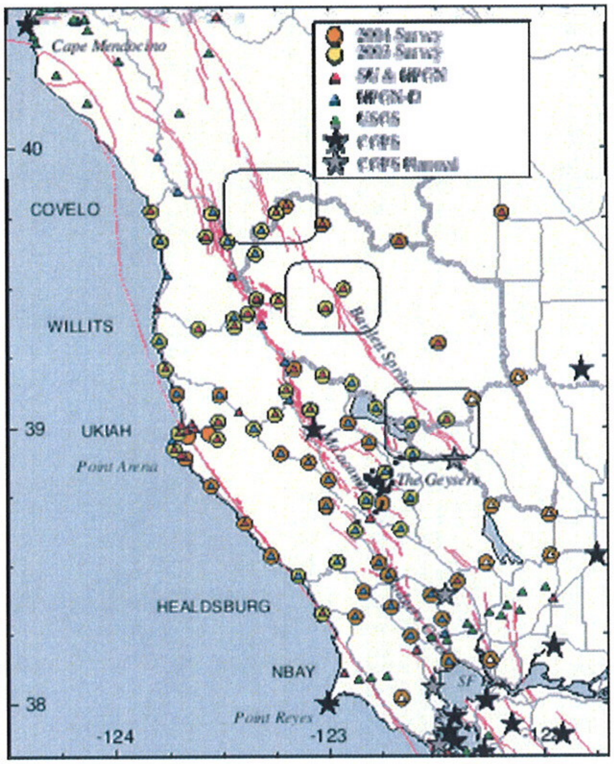

Figure 1. GPS sites along the northern San Andreas fault system. Light circles, sites that were observed in early 2003. Dar circles, 2004 surveyed sites. Profile names are capitalized. USGS conduct surveys along the NBAY profile and near Cape Mendocino. Only one continuous GPS station (HOPB) operated in this region during the study period. Rounded boxes indicate special focus areas along the Bartlett Springs fault.

Results

Geodetic Measurements

The survey of the 4 primary profiles was conducted during January-March 2003 after verifying the benchmarks were still suitable for GPS observations, and picking or installing substitutes at the few that were not. Most of the stations were occupied for 6.5-8 hours on two different days. Some sites in the Central Valley or in the higher portions of the Coast Ranges that were not occupied due to weather or logistical considerations will be included in the Fall 2003 survey. Altogether, 43 site positions were measured during 94 session occupations, with the assistance of students and staff of the BSL.

We processed the data using GAMIT/GLOBK software using many of the same techniques used to process the BARD observations Murray and Segall, 2001). These distributed processing methods allow the solutions to be combined in a self-consistent fashion with other solutions, such as for the BARD network, and for more global networks provided by the SOPAC analysis center, using Kalman filtering techniques, providing a well-defined velocity reference frame with respect to the stable North America. We reprocessed the older observations in GAMIT/GLOBK to tie all the northern California observations together in a self-consistent manner. These data sets include Stanford surveys of the profiles, NGS surveys of the HPGN network, USGS surveys of the Covelo profile, and Caltrans surveys of the HPGN-Densification sites.

Deformation

Figure 2 shows site velocities estimated using the GAMIT/GLOBK software package for the 1994-2004 period relative to stable North America, as defined by a set of 20 fiducial stations. We are currently processing the data from the most recent surveys that will provide new estimates of velocities for sites between the southern and northern profiles shown. Most of the velocities are derived from data spanning 8-10 years, whereas those with the largest error ellipses include data from only a 4 year span. The easternmost stations exhibit motions typically associated with Sierran-Great Valley block (ORLA: 12.5 mm/yr NW). The westernmost sites are moving close to the Pacific plate rate (PTAR: 45.9 mm/yr NW). Fault-normal contraction is observed east of the Ma'acama fault, in the region of the Coast Ranges near the Central Valley where similar contraction has been observed elsewhere (e.g., *Murray and Segall,* 2001).

Also shown in Figure 2 are velocities predicted by angular velocity-fault backslip modeling techniques (e.g., *Murray and Segall*, 2001) to account for both far-field plate motions and interseismic strain accumulation. We are developing a 3D fault model and applying the same modeling approach that we used in our BAVU study of the San Francisco Bay area (*d'Allesio et al.,* 2005). Preliminary results show that the agreement between observed and predicted velocities is typically less than the 2 mm/yr level. Misfits are larger in a few areas close to faults, such as along the central Ma'acama and near the MTJ, that should be decreased with further refinement of the fault geometry. Total deformation across the San Andreas fault system is 38 mm/yr, in agreement with previous studies, but deep slip is concentrated on the Ma'acama fault (24 mm/yr) and on the Bartlett Springs fault (10 mm/yr), with only 4 mm/yr on the San Andreas. We are currently investigating this result, which is due in part to the high-degree of correlation between the slip rates on the 3 faults, and will test methods for adding geologic and other information using Bayesian techniques, which should reduce the correlations on slip rates and provide better resolution on other parameters such as locking depths.

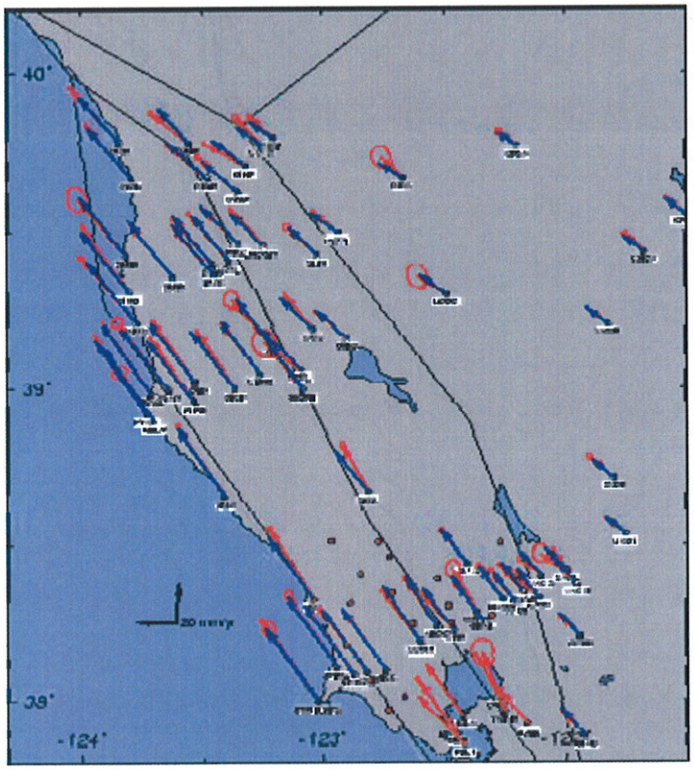

Figure 2. Velocities of sites in the Coast Ranges relative to North America with 95% confidence regions assuming white-noise process only. Included are sites from this study plus sites from the BARD continuous network and the USGS North Bay profile. Arrows with ellipses, observed velocities. Arrows without ellipses, velocities predicted from angular velocity-backslip block models assuming block boundaries (heavy black lines). We assume Pacific, North America, and Sierran-Great Valley blocks, plus 2 small blocks between the San Andreas, Ma'acama, and Bartlett Springs faults. The most significant misfits, such as near Cape Mendocino, can be reduced by refining the fault geometry. Additional sites in the southern portion of the network (circles), have been recently remeasured.

We also worked with D. Agnew (UCSD), R. King (MIT), and Z-K. Shen (UCLA) to combine these results with the BAVU, SCEC Crustal Motion Model (CMM 3.0), and other studies to provide an integrated California-wide velocity field. The preliminary velocity field is shown in Figure 3 and includes over 2000 stations. Additional stations will be included from the Cape Mendocino triple junction region. Results from this study will be used to develop a state-wide deformation and fault slip model that will be incorporated into a hazard assessment project by the Working Group on California Earthquake Probabilities under the auspicies of the USGS. Preliminary results of the WGCEP project are expected in mid-2006.

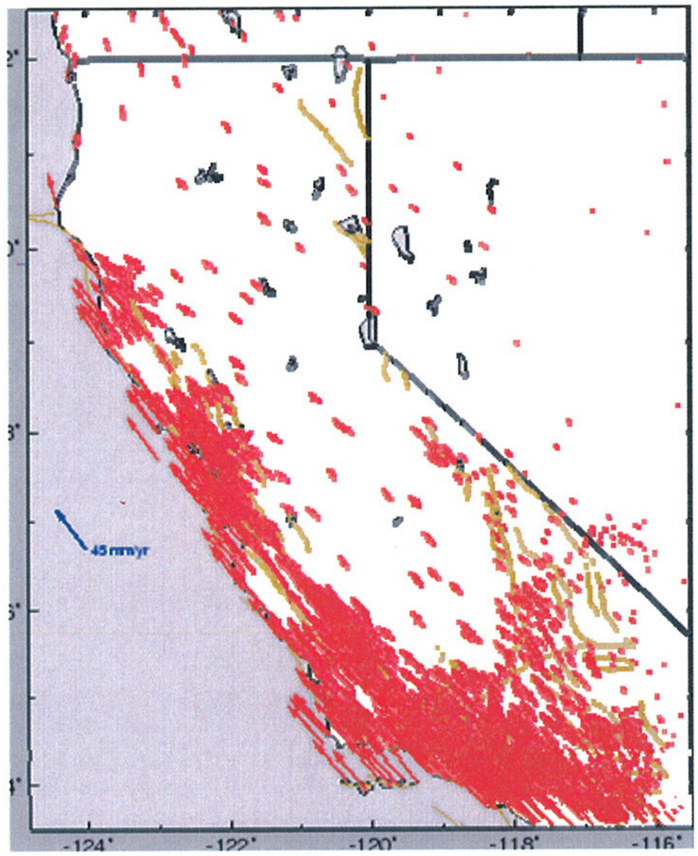

Figure 3. Velocities of sites in California relative to stable North America from a combination of velocities from this study, BAVU, the SCEC Crustal Motion Map, and other studies.

Acknowledgements

We thank André Basset, Maurizio Battaglia, Dennise Templeton, and especially Todd Williams for assistance conducting the survey.

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